THREE-DIMENSIONAL CLADDING WITH BIO-BASED MATERIALS:

a parametric design following the seamless tiling concept

Graduation Reflection

Laura Romano

8.1_ GRADUATION PROCESS

This thesis aims to explore and provide a new three-dimensional design system that takes care of innovation while respecting and enhancing circular strategies.

This research started by following a case studies observation of three-dimensional claddings and their usually used materials.
From this observation, the goal was to understand the actual environmental impact of realizing such designs and the possible beneficial impact that the thesis could have on the building market.

Following the information obtained regarding the impact that usual materials used for three-dimensional cladding are causing on the environment, the analysis of how to create a more circular option began. Therefore, the thesis principle is innovation through design and materiality.

As the first step for the design concept, an attempt has been made to analyze three-dimensional case studies that start from a bio-based material to compose the design. However, results have yet to appear. In fact, from the personal experience absorbed with the literature research, either performative designs or circular experimental materials are usually developed. Consequently, finding references to understand the proper method of approach has been complicated.
Nevertheless, this shows the innovation in considering design, materials, and manufacturing process simultaneously with a circular point of view.

In realizing this thesis, a method was implemented that combined two simultaneous kinds of research: on one side, the research by design, and on the other, the material understanding. This method has been slightly changed from the usual correlation between research by design and experimentation since, given the timing of a master thesis and the initially set objectives - which were developing both design and material- there was no possibility of concluding in time.

Consequently, the aim moved to configure the design by looking for a material already certified in the building market that could reflect the given requirements, explained in Chapter 2.4.
The research-by-design approach and the theoretical understanding of potential materials and manufacturing processes have led to qualitative results. However, sometimes the concomitance could throw off the balance of the two topics and therefore develop one more than the other: this was a thread that could have continued throughout the drafting of

the thesis, but which fortunately did not happen.
Once the concept design was established, this thread was no longer present; on the contrary, simultaneity gave the opportunity to fully understand the benefits and disadvantages of each topic, creating a product that is the summary and balance of what has been learned.

Therefore, the peak in the relationship between research and design occurs following the concept design. Constraints, parameters, and variables were closely related to the choice of material and - subsequently, to the manufacturing process - the circular design strategies explained in Chapter 2.2 and then pre-settled and validated in Chapter 3.1.

Following this concurrency, it was possible to create a design that responded to circular principles without abandoning the versatility given by the computational configuration created.

8.2_ GRADUATION RELEVANCE

The proposed design system presented in this study holds significant social, professional, and scientific relevance.

First and foremost, the primary objective of this thesis is to offer a viable design system that can be directly implemented as a product. Consequently, it operates within the cognitive framework and fosters innovation based on real-life aspects rather than experimental ones. By prioritizing the objective of “connecting the dots” instead of experimentation, the potential for social and professional impacts is heightened.

The central focus of this research is to discover a suitable and certified alternative for materials that, as discussed in Chapter 2, negatively impact the environment due to material extraction, production processes, energy consumption, and waste generation. This thesis convincingly demonstrates that it is feasible to transition to new material, thereby adding value to three-dimensional geometries.

Therefore, this new vision contributes to shifting the construction market towards the circular economy by proposing a new application system that can substitute those more traditional materials that consume the material, energy, and waste, impacting the environment.

To comprehensively evaluate each facet of the research and product realization, a detailed analysis will be conducted, considering the four domains of circularity: *design*, *material*, *manufacturing*, and *management*.

FOUR DOMAIN OF CIRCULARITY

DESIGN

The panel design consists of a squared-modular panel composed of sharp three-dimensional angles ending in a protruded core called a focal point.

As explained in Chapter 3.1, this concept is to break the traditional way of associating design with materiality by incorporating a design inspired by the folding process commonly employed in metal product manufacturing. As a matter of fact, this design highlights the material's ability to withstand complex shapes, making it an optimal alternative to the aforementioned materials.

Furthermore, this innovative design has been developed to promote sustainability. Design strategies that facilitate circularity in the outcome have been employed. Modularity and flexibility are the primary and fundamental principles considered during the design process. As a solution, the seamless tiling approach was devised by maximizing versatility and creativity while respecting the environment and minimizing energy consumption, waste generation, and costs. As extensively explained, this approach offers significant flexibility in composing the panel and the façade.To implement such strategy, Parametric design has been used as a primary tool, enabling freedom of expression and establishing a new foundation for future applications. Besides that, other circular strategies such as dematerialization, design for disassembly and material choice have been applied: the latter will be explained in the next section.

After showing the system, a final product has been realized. Therefore, the panel freedom has been stabilized while showing the flexibility of the actual product for the realization of different façades. The individual elements for composing the flexible façade are panels measuring 60cm x 60cm and weighing 4.7 kg each. These panels can be easily assembled and disassembled without requiring specialized machinery. Moreover, because of the weight and the limited size, there is no need for extravagant and impacting transportation.

Because of how it has been assembled and the chosen components, the façade is ventilated. Therefore, the arrangement of such three-dimensional panels, which extend inward from the façade, requires a gap between the panel and the wall system, functioning eventually as a natural ventilation chamber.

However, it is essential to acknowledge a primary limitation concerning the representation of complex geometries. As explained in Chapter 7, given the sharp nature of the design, reproducing more organic macro-geometries becomes challenging unless the parametric panel variables are distorted to realize a smoother configuration.

MATERIAL

The material choice, extensively discussed in Chapter 2 and 5, is the Nabasco 80s series, specifically Nabasco 8012.
Nabasco 8012 is a certified material which has been largely tested in different configurations and functionalities.
Composed of reed fibers obtained from the waste generated by the roof construction industry, calcite sourced from the waste produced by drinking water companies, and a partially bio-based resin, Nabasco 8012 exemplifies the utilization of by-products in its composition. By incorporating these waste materials, a significant portion of the final material is derived from repurposed sources.

Furthermore, Nabasco 8012 is a bulk-mounding compound that exhibits a dough-like consistency. This fluid yet dense state allows for substantial flexibility in realizing the end product, which was a primary criterion for selecting this material.

However, it is important to note that the resin, as previously mentioned, is only partially bio-based, as it is derived from leftover biofuel resources. Nevertheless, efforts are already underway at NPSP to explore more circular options that rely on fully bio-based materials possessing similar mechanical properties. These alternatives, because more experimental, have not yet obtained certification.

Therefore, given the criteria of the graduation research, the material decision was made to prioritize a certified product over a more experimental but potentially more circular material. This choice ensures the fulfillment of academic requirements while still acknowledging the ongoing exploration of circular options by NPSP.

MANUFACTURING

The manufacturing process employed for creating the panel made of Nabasco 8012, as discussed in Chapters 2.5 and 2.6, is the hot-press process. As noted by Kula et al. (2013), this process offers a high degree of flexibility and versatility in shaping the material. It enables the material to be easily moulded into intricate and complex shapes. As explained earlier, the combination of this process with the material's unique properties grants the freedom to explore and challenge three-dimensionality in design.

In the research context, where design, material, and manufacturing processes are interconnected, the manufacturing process does not represent an innovative aspect. Instead, together with the material, it serves as a tool for realizing the desired innovation.

However, it is essential to acknowledge that the hot-press process needs metals for the moulds. As explained in Chapter 5, the mould material must possess high-temperature and pressure resistance while facilitating heat transfer to the material without deformation.

Consequently, producing aluminum required for the moulds becomes an unavoidable environmental impact associated with manufacturing. The aluminum will undergo further processing through CNC machining to create the moulds.

To mitigate this impact, a dematerialization strategy has been implemented as extensively explained.
The overall environmental footprint is reduced by creating only six moulds capable of producing various configurations.
This strategic approach minimizes the need for additional mould production, mitigating the environmental consequences of raw material extraction and aluminum production.

MANAGEMENT

While the management domain was not a primary focus of this research, it is important to consider certain aspects in order to provide a comprehensive understanding.

The design system and resulting product have a significant impact on management practices. Analyzing the R-strategies presented in Figure 22, it becomes apparent that the final product aligns with both the upper part macro-group, which - *by rethinking* - emphasizes resource efficiency and minimizing environmental impact, and the middle part, which extends the lifespan of by-products such as the Nabasco 8012 components by *repurposing* with a new function.

This shift in design and product approach also necessitates a change in resource management and related policies. The realization of the design's potential leads to a broader understanding of resources and their value not only during their initial use but throughout their entire life cycle. This holistic perspective influences the way materials are valued and how resources are managed and allocated.

Furthermore, recognizing the significance of waste and the potential to create strong and flexible materials from it, waste management policies should be prioritized to transition towards more effective and appropriate waste management practices. This highlights the importance of developing policies that emphasize proper waste handling and utilization, taking into account the potential of waste as a valuable resource.

COMPARISON

After conducting a comprehensive analysis of the product based on the four domains of circularity, a comparative evaluation will be conducted to assess its performance against existing products. However, it is important to note that the management aspect was not included in the literature research and, therefore, will be omitted from the evaluation.

DESIGN

The developed system presented in this study introduces new approaches and possibilities for the building market.

Through its design - and the consequent prototype realization - the system showcases the potential of bio-based materials to be shaped in unconventional ways, departing from the typically offered flat façade designs. The accompanying images below depict some examples of the façades created using bio-based materials, demonstrating both flat compositions and, in the case of The Exploded View Beyond Building project utilizing Nabasco 8010 (Fig. 142), bas-relief designs.

Therefore, until now, the prevailing focus has primarily been on the materiality of these circular panels, with limited exploration of their geometric possibilities. Thus, the developed system unveils the potential of simultaneously exploring both materiality and geometry while encompassing all the aforementioned domains of circularity.

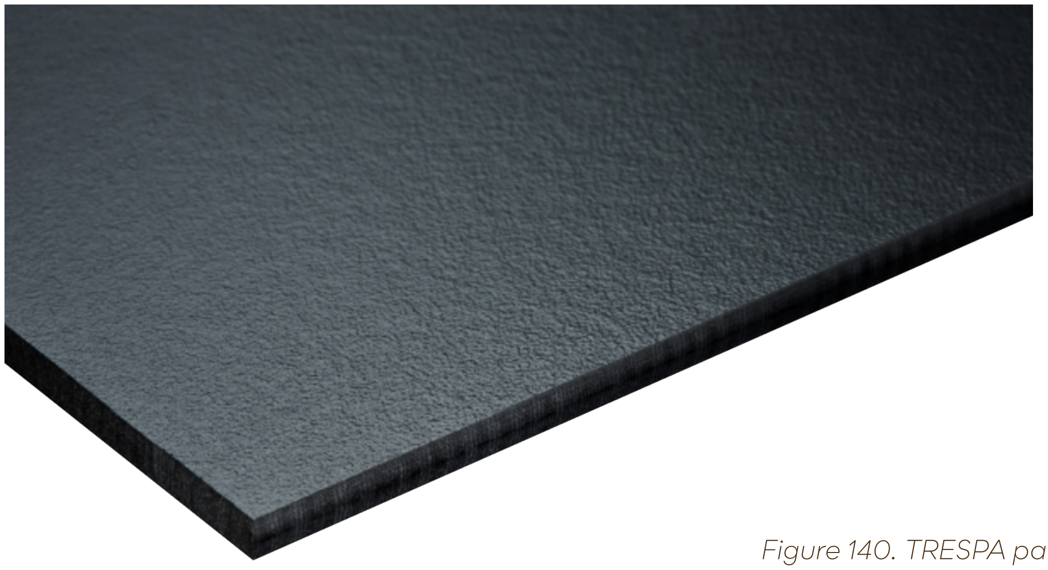

Figure 140. TRESPA panel
Source: TRESPA (n.d.)

Figure 141. RESYSTA panel
Source: RESYSTA (n.d.)

Figure 142. Nabasco 8010 panel in The Exploded View Beyond Building
Source: NPSP (n.d.)

MATERIAL

To adequately assess the potential of the developed panel's three-dimensionality, a comparison with conventional three-dimensional cladding materials is conducted. In order to ensure a comprehensive material comparison, it is necessary to assume that the developed panel incorporates all the materials examined in the case studies presented in Chapter 2. It should be noted that for the purpose of this analysis, an equal volume is considered for all the cases, which will be the volume of the final product (0.00288 m3).

The materials included in the comparison are as follows:

- Aluminium with Bronze Coat
- Aluminium Composite (Aluminium foils + plastic core)
- Laminated Glass
- Glass Fiber Reinforced Concrete (GFRC)
- Nabasco 8012

The lifespan of a material is an important consideration when evaluating its suitability for a particular application. Metals such as aluminium and steel are favored due to their long-lasting nature, which reduces the frequency of replacements. Comparing this innovative material to traditional ones is crucial to assess its practicality and determine if it offers advantages in terms of lifespan, thereby minimizing material usage, energy consumption, and waste generation.

In many cases, it was not possible to find exact matches for the materials used in the case studies. Therefore, the comparison will be based on the general macro-group of materials, and alternative sources will be used to provide insights. This is because the lifespan of a material depends on various factors such as quantity, exposure, and climate conditions. The aim is to gain a generalized understanding of whether the lifespan of Nabasco 8012 can be comparable to that of traditional materials.

For example, Northeastern University's cladding utilizes aluminium coated with bronze, but since the bronze layer is thin, it will not be considered. Aluminium, known for its considerable lifespan, typically exceeds 75 years (Reynaers, 2022). In contrast, the internal cladding at Theatre Zuidplein, consisting of 5mm of plastics and 1mm of aluminium, may last only around 5 years before requiring replacement, which is relatively short (Alutech, n.d.).

In the case of laminated glass, specifically the manufacturer Harpa Concert Hall, it is expected to last approximately 30 years (Schollglas, n.d.). As for Glass Fiber Reinforced Concrete, the lifespan range generally extends to 50 years or more (Rieder, n.d).

Regarding Nabasco 8012, it is important to acknowledge that laboratory tests have indicated a projected lifespan ranging from 50 to 100 years (Bottger, 2023). However, it should be noted that these values have not been validated under real-world conditions, and there is inherent uncertainty regarding its performance in specific situations.

From a theoretical standpoint, the lifespan of Nabasco 8012 demonstrates promising results - as shown in Fig. 143 - , positioning it favorably in comparison to traditional materials. It is essential, though, to exercise caution when drawing conclusions, as further testing and validation in real-world applications would be necessary to confirm its long-term durability and performance.

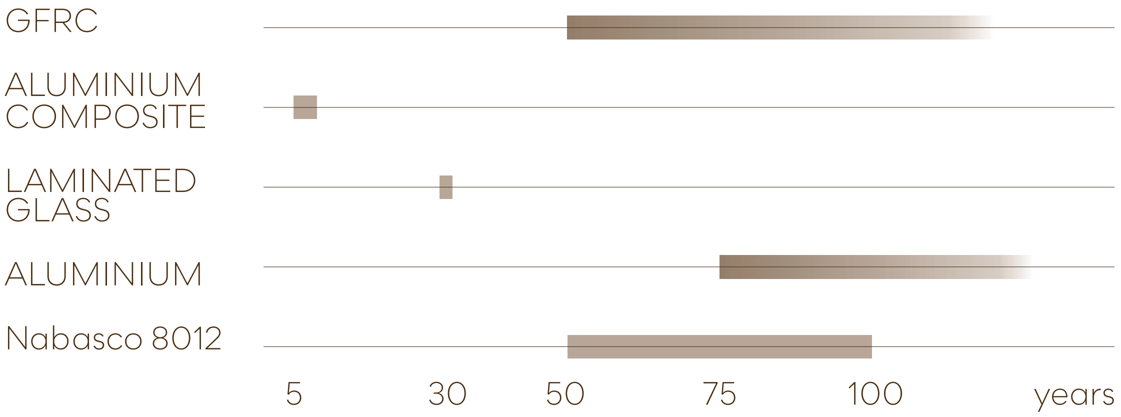

Figure 143. Life span Selected materials own ill.

Another crucial aspect that warrants careful consideration in the analysis is the carbon footprint associated with the production of these materials. However, despite the efforts, obtaining precise carbon footprint values for the specific case studies examined has proven challenging, necessitating the adoption of a similar approach as previously described.

Based on the available information, as depicted in Figure 144, both laminated glass and aluminium composites exhibit comparable carbon footprint values, averaging around 7 $kgCO_2eq/kg$ - respectively 7.61 and 6.56 $KgCO_2eq/Kg$ - (Schollglas, n.d.) (Alcotek, 2020). Conversely, aluminium demonstrates a higher carbon footprint, with values reaching 14.78 $KgCO_2eq/Kg$ (Alupro, n.d.). In contrast, NPSP has conducted a comprehensive evaluation of Nabasco 8012's carbon footprint, which encompasses both material production and the manufacturing process, resulting in a carbon footprint below 1 $kgCO_2eq/kg$ (Bottger, 2023). Regrettably, specific carbon footprint values for glass reinforced concrete were not identified during the research.

In conclusion, although precise carbon footprint values for all the materials examined were not readily available, it is evident that Nabasco 8012 possesses a comparatively lower carbon footprint. This conclusion is supported by the findings presented by Bottger (2023), which indicate that the carbon footprint values for Nabasco 8012 include not only the material production but also the associated manufacturing process.

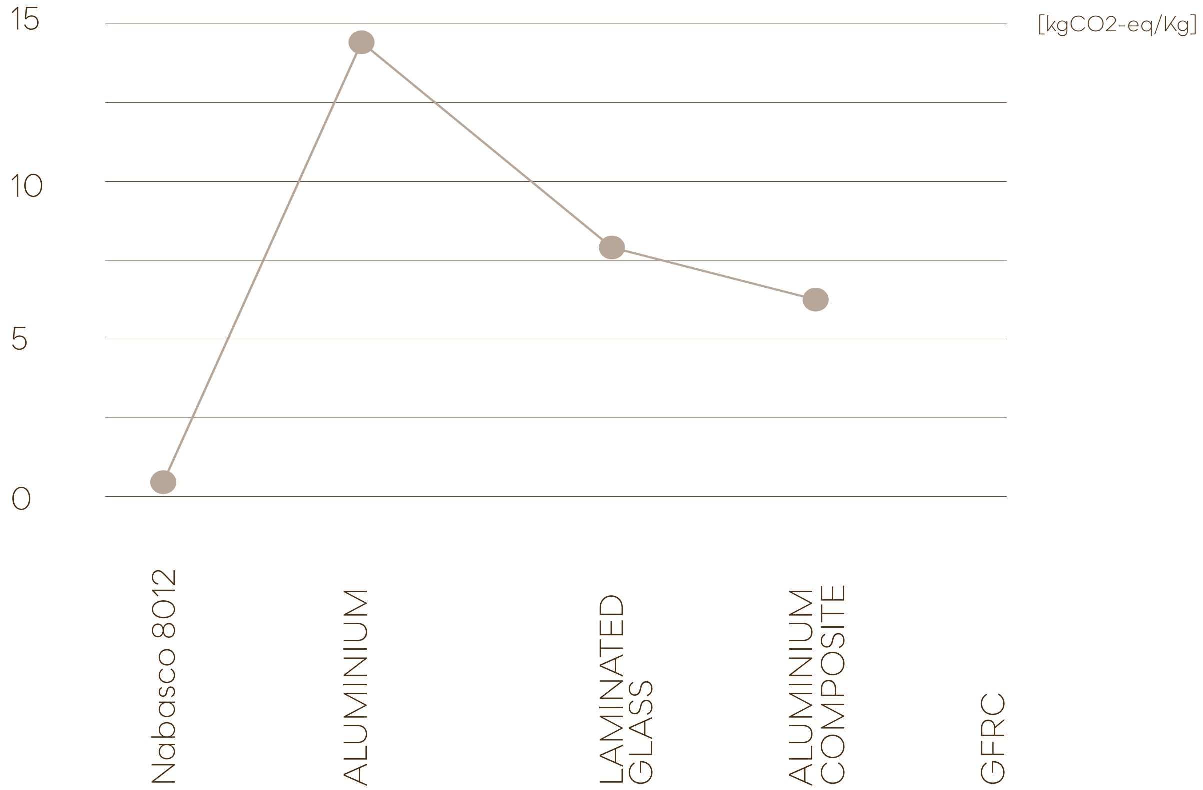

Figure 144.Carbonfootprint felected materials own ill.

In evaluating the overall sustainability of Nabasco 8012, it is imperative to consider the end-of-life aspect and gain a comprehensive understanding of how this material performs throughout its life cycle. While all the mentioned materials are recyclable, Nabasco 8012 offers a distinct advantage by providing the opportunity for repurposing.

As discussed in detail in Chapter 2.4, when Nabasco 8012 reaches the end of its useful life, it can be efficiently shredded and repurposed as filler material for the production of new panels. This innovative approach not only extends the material's lifespan but also contributes to a significant reduction in waste generation. By transforming the panel into a valuable by-product, the utilization of Nabasco 8012 promotes the principles of a circular economy, emphasizing resource efficiency and minimizing environmental impact, as explained in Fig. 22.

MANUFACTURING

The hot press manufacturing process employed for the production of Nabasco 8012 panels is not considered an innovative process in itself. However, it is important to note that certain energy-intensive processes are still involved in this manufacturing technique. Comparing the hot press process to other manufacturing processes is challenging due to the complexity and diversity of processes employed to produce a final panel. Attempting to assess and evaluate each process comprehensively would result in a generalized and complicated analysis.

Nevertheless, the development of Nabasco 8012 panels incorporates a positive aspect in terms of manufacturing. By approaching the design *rethinking* method, careful consideration has been given to reducing the number of manufactured panels, which consequently minimizes the amount of material and energy required. To illustrate this point a contrasting scenario will be considered. In the case of the project “The Broad” discussed in Chapter 2.1 (Fig. 14), a staggering 380 moulds were necessary to produce 2500 panels. In contrast, with the developed design using Nabasco 8012,taking into account the reusability of aluminum moulds for at least 500 cycles - as mentioned by Bottger in 2023 - it becomes apparent that by employing this method, it would be possible to achieve the same number of panels with a reduction of 374 moulds.

This example highlights the significant reduction in the number of moulds and associated energy-intensive processes achieved through the innovative design approach. By streamlining the manufacturing process, the environmental impact in terms of material usage and energy consumption can be considerably mitigated.

CONCLUSION

In conclusion, the development of the final product presents significant opportunities within the four domains of circularity. Through its own inherent properties and by comparison to traditional materials, it demonstrates the potential for enhanced sustainability and resource efficiency. While further research is warranted, given the relative novelty of this material and the only scaled prototyping test for the design realization, it is clear that the design system in combination with Nabasco 8012, has the potential to contribute significantly to sustainable practices, fostering a circular economy and minimizing environmental impact.

8.3_ FUTURE RESEARCH

As this study progressed, numerous potential further steps emerged, each intended to explore the different aspects involved in this thesis.

MATERIAL EXPLORATION

Considering the chosen certified material as a product non-completely bio-based because of the resin, a material test and exploration could be assessed. Consequently, considering the fundamental principles of this thesis, it would be intriguing to contribute to developing and providing a bio-based resin while still maintaining the efficient mechanical properties of the chosen material.

Mould MATERIAL EXPERIMENTATION

The material realization needs a metal that withstands high temperatures and can conduct heat. Metals are the most appropriate ones; however, as explained in the previous chapters, the energy required and the carbon footprint emitted are impacting mainly the environment.
Further research could be studying a new material that could replace the aluminum or steel moulds that withstand the same requirements.

PANEL DESIGN ADAPTABILITY

The design systems propose a panel design. However, given the scenario, infinite configurations can be created by respecting the seamless tiling concept.
Potential further steps could be creating different designs and, eventually, tools for letting the user choose which configuration suits their preference the best.

PANEL DESIGN ADAPTABILITY

As explained in Chapter 7, the design is related chiefly to sharp-looking three-dimensionality. Further research by design could be handled to understand how to include more organic shapes in this flexibly developed rule.

DIGITAL DESIGN

The suggested workflow for generating the façade's geometry has the potential for further refinement, aiming to evolve into a comprehensive parametric design tool that architects and engineers can readily employ. The tool could incorporate parameters tailored explicitly to the moulding process to expand its functionality.

STRUCTURAL OPTIMIZATION

Attention is given to the material use of moulds. Thanks to the parametric design of the developed panels, just six moulds have been shaped, offering the chance to have infinite design configurations.
Since the project covers the material amount for resources and energy demand, a structural optimization for minimizing the material used within the panel and the mould could be implemented in a thesis storyline.

CIRCULAR SUBSTRUCTURE AND STRUCTURE

In conclusion, considering the focus on altering conventional materials to create three-dimensional claddings, it would be prudent to apply the same level of precision in comprehending how to adopt circular principles in the elements behind the façade, such as the substructure, structure and wall components.
The substructure in the proposed design heavily relies on metal connections. As discussed in Chapter 5, this decision was made to preserve the integrity of mould production while offering designers flexibility in their choices. Additionally, it catalyzes future advancements in connection techniques, given a flat surface that does not impede other design possibilities.

Therefore, new connection systems can be designed to respond to both the rotational and mass of the panel (4.7kg) by reducing impacting materials or using less impacting materials than conventional connections.

THERMAL PERFORMANCE

Since the final shape permits the ventilated façade implementation, thermal simulations and analysis can be made to understand the design's thermal performances and optimize it.